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REPORT NO. T18-88

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# COGNITIVE PERFORMANCE, MOOD STATES, AND ALTITUDE SYMPTOMATOLOGY IN 13-21% OXYGEN ENVIRONMENTS

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U S ARMY RESEARCH INSTITUTE
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ENVIRONMENTAL MEDICINE
Natick, Massachusetts

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UNITED STATES ARMY
MEDICAL RESEARCH & DEVELOPMENT COMMAND

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SECURITY CLASSIFICATION OF THIS PAGE

# REPORT DOCUMENTATION PAGE

Form Approved OMB No 0704-0188

| | |
|---|---|
| 1a. REPORT SECURITY CLASSIFICATION<br>Unclassified | 1b. RESTRICTIVE MARKINGS<br>None |
| 2a. SECURITY CLASSIFICATION AUTHORITY | 3. DISTRIBUTION/AVAILABILITY OF REPORT<br>Approved for public release; distribution is unlimited. |
| 2b. DECLASSIFICATION/DOWNGRADING SCHEDULE | |
| 4. PERFORMING ORGANIZATION REPORT NUMBER(S) | 5. MONITORING ORGANIZATION REPORT NUMBER(S) |
| 6a. NAME OF PERFORMING ORGANIZATION<br>US Army Research Institute of Environmental Medicine<br>6b. OFFICE SYMBOL (If applicable)<br>SGRD-UE-HP | 7a. NAME OF MONITORING ORGANIZATION<br>US Army Medical Research and Development Command |
| 6c. ADDRESS (City, State, and ZIP Code)<br>Natick, MA 01760-5007 | 7b. ADDRESS (City, State, and ZIP Code)<br>Ft. Detrick<br>Frederick, MD 21701-2015 |
| 8a. NAME OF FUNDING/SPONSORING ORGANIZATION<br>Same as 6a.<br>8b. OFFICE SYMBOL (If applicable) | 9. PROCUREMENT INSTRUMENT IDENTIFICATION NUMBER |
| 8c. ADDRESS (City, State, and ZIP Code)<br>Same as 6c. | 10. SOURCE OF FUNDING NUMBERS<br>PROGRAM ELEMENT NO. 61102A<br>PROJECT NO. 3M161102BS15<br>TASK NO. CA<br>WORK UNIT ACCESSION NO. DA0C6122 |

11. TITLE (Include Security Classification)
Cognitive Performance, Mood States, and Altitude Symptomatology in 13-21% Oxygen Environments

12. PERSONAL AUTHOR(S)
B.L. Shukitt, R.L. Burse, L.E. Banderet, D.R. Knight*, A. Cymerman

| 13a. TYPE OF REPORT | 13b. TIME COVERED | 14. DATE OF REPORT (Year, Month, Day) | 15. PAGE COUNT |
|---|---|---|---|
| Tech Report | FROM 3/87 TO 4/87 | 88, June, 1 | 44 |

16. SUPPLEMENTARY NOTATION
*US Naval Submarine Medical Research Laboratory
Groton, Connecticut 06349-5900

| 17. COSATI CODES | | |
|---|---|---|
| FIELD | GROUP | SUB-GROUP |
| | | |
| | | |

18. SUBJECT TERMS (Continue on reverse if necessary and identify by block number)
cognitive performance, mood, symptoms, AMS, altitude, low oxygen environments, Clyde Mood Scale, ESQ, arterial oxygen saturation, normabaric and hypobaric oxygen concentrations

19. ABSTRACT (Continue on reverse if necessary and identify by block number)


To reduce the risk of and damage from fires, naval engineers have suggested reducing the oxygen concentration in submarines below the normal ambient level of 21% (PO2 = 159 torr). However, reductions to 13% oxygen (PO2 = 99 torr) may produce decrements in mental and physical performance, changes in mood states, or symptoms of acute mountain sickness (AMS). To investigate these possibilities, thirteen male sailors were confined and tested in a hypobaric chamber for fifteen days, where they experienced oxygen concentrations of 21, 17, 21, 13, and 21% for three days at each concentrations with 0.9% carbon dioxide and the balance nitrogen. The subjects took one 30-minute battery of cognitive tasks most mornings and a different 30-minute battery of cognitive tasks every afternoon. They also completed the Clyde Mood Scale and the Environmental Symptoms Questionnaire (ESQ) every afternoon following cognitive testing.

(Continued)


| | |
|---|---|
| 20. DISTRIBUTION/AVAILABILITY OF ABSTRACT<br>☒ UNCLASSIFIED/UNLIMITED ☐ SAME AS RPT. ☐ DTIC USERS | 21. ABSTRACT SECURITY CLASSIFICATION<br>Unclassified |
| 22a. NAME OF RESPONSIBLE INDIVIDUAL<br>Louis E. Banderet | 22b. TELEPHONE (Include Area Code) (508) 651-4858<br>22c. OFFICE SYMBOL SGRD-UE-HP |

DD Form 1473, JUN 86

Previous editions are obsolete.

SECURITY CLASSIFICATION OF THIS PAGE

UNCLASSIFIED

No cognitive tasks were found to be adversely affected by 17% oxygen (PO2 = 129 torr), even when the ambient pressure was reduced on the third day for 7.5 hours to produce a PO2 equivalent to that of normobaric 13% oxygen. No changes in mood states were observed at normobaric 17% oxygen, but "Clear Thinking" and "Dizziness", factors on the Clyde Mood Scale, were adversely affected by the reduction in pressure on the third day of the 17% condition. At 13% oxygen, one cognitive task, "Computer Interaction", and the mood factors of "Sleepiness" and "Dizziness" were adversely affected on the first day. Cognition and mood were both unaffected on the second and third days at 13% oxygen, however.

No individual reported either cerebral or respiratory forms of AMS (AMS-C and AMS-R, respectively) on any of the control days at 21% oxygen or on the two days' exposure to normobaric 17% oxygen. After 7.5 hours exposure to hypobaric 17% oxygen, however, two individuals reported AMS-C; one of these also reported AMS-R. On the first day of exposure to 13% oxygen, five of the thirteen subjects reported AMS-C; four of these also reported AMS-R. By the second day, three subjects had recovered to control scores, but the other two remained affected by AMS through the end of the third day. Arterial oxygen saturation was not significantly affected under 17% oxygen, but it was significantly reduced from 98% to 92% under 13% oxygen. There were no significant differences in saturation between those individuals suffering from AMS and those not, however.

It appears that normobaric oxygen concentrations as low as 17% are not likely to produce adverse effects on cognition, mood states, or AMS symptomatology. Oxygen concentrations as low as 13% are likely to adversely affect some performance tasks and moods, however, as well as induce AMS in about one-third of the exposed individuals. These effects are quite similar to those observed in mountain climbers at the same PO2, whose responses well may be predictive of the effects of oxygen concentrations in between 13 and 17% oxygen. Keywords: performance human; decreased oxygen supply; hypoxia; acclimatization; [illegible]

Human subjects participated in these studies after giving their free and informed voluntary consent. Investigators adhered to AR 70-25 and USAMRDC Regulation 70-25 on Use of Volunteers in Research. Furthermore, the protocol and procedures for the study were approved by the Committee for Protection of Human Subjects, Naval Submarine Medical Research Laboratory, Groton, Connecticut.

The views, opinions, and/or findings contained in this report are those of the author(s) and should not be construed as an official Department of the Army or Department of the Navy position, policy, or decision, unless so designated by other official documentation.

## ACKNOWLEDGMENTS

The authors wish to thank SSG Michael Walthers of the Information Management Branch of the US Army Research Institute of Environmental Medicine (USARIEM) for his skillful programming of the cognitive tasks. We also acknowledge the technical assistance of following personnel in the Health and Performance Division of USARIEM: SP4 David Welch, SP4 Linda Gowenlock, SSG Douglas Dauphinee, SGT Anthony Marshall, SP4 Jack Stoskopf, and Ms Nancy Morris. We also thank Mr James Devine and his crew who operated the USARIEM Altitude Chamber, and CPO Briones and his personnel from the Naval Submarine Medical Research Laboratory, Groton CT.

We are particularly grateful to the volunteer test subjects from the Naval Submarine Base in Groton, Connecticut and the Portsmouth Naval Shipyard in Kittery, Maine. Their patience, stamina, and enthusiastic spirit helped immeasurably in the smooth completion of this project.

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Technical Report

No. T18-88

# COGNITIVE PERFORMANCE, MOOD STATES, AND ALTITUDE SYMPTOMATOLOGY IN 13-21% OXYGEN ENVIRONMENTS

B.L. Shukitt, R.L. Burse, L.E. Banderet, D.R. Knight, & A. Cymerman

June 1988

US Army Research Institute of Environmental Medicine
Natick, Massachusetts 01760-5007
and
US Naval Submarine Medical Research Laboratory
Groton, Connecticut 06349-5900

Project Reference
3M161102BS15

Series HP

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ABSTRACT

To reduce the risk of and damage from fires, naval engineers have suggested reducing the oxygen concentration in submarines below the normal ambient level of 21% ($PO_2$ = 159 torr). However, reductions to 13% oxygen ($PO_2$ = 99 torr) may produce decrements in mental and physical performance, changes in mood states, or symptoms of acute mountain sickness (AMS). To investigate these possibilities, thirteen male sailors were confined and tested in a hypobaric chamber for fifteen days, where they experienced oxygen concentrations of 21, 17, 21, 13, and 21% for three days at each concentration with 0.9% carbon dioxide and the balance nitrogen. The subjects took one 30-minute battery of cognitive tasks most mornings and a different 30-minute battery of cognitive tasks every afternoon. They also completed the Clyde Mood Scale and the Environmental Symptoms Questionnaire (ESQ) every afternoon following cognitive testing.

No cognitive tasks were found to be adversely affected by 17% oxygen ($PO_2$ = 129 torr), even when the ambient pressure was reduced on the third day for 7.5 hours to produce a $PO_2$ equivalent to that of normobaric 13% oxygen. No changes in mood states were observed at normobaric 17% oxygen, but "Clear Thinking" and "Dizziness", factors on the Clyde Mood Scale, were adversely affected by the reduction in pressure on the third day of the 17% condition. At 13% oxygen, one cognitive task, "Computer Interaction", and the mood factors of "Sleepiness" and "Dizziness" were adversely affected on the first day. Cognition and mood were both unaffected on the second and third days at 13% oxygen, however.

No individual reported either cerebral or respiratory forms of AMS (AMS-C and AMS-R, respectively) on any of the control days at 21% oxygen or on the two days' exposure to normobaric 17% oxygen. After 7.5 hours exposure to hypobaric 17% oxygen, however, two individuals reported AMS-C; one of these also reported AMS-R. On the first day of exposure to 13% oxygen, five of the thirteen subjects

reported AMS-C; four of these also reported AMS-R. By the second day, three subjects had recovered to control scores, but the other two remained affected by AMS through the end of the third day. Arterial oxygen saturation was not significantly affected under 17% oxygen, but it was significantly reduced from 98% to 92% under 13% oxygen. There were no significant differences in saturation between those individuals suffering from AMS and those not, however.

It appears that normobaric oxygen concentrations as low as 17% are not likely to produce adverse effects on cognition, mood states, or AMS symptomatology. Oxygen concentrations as low as 13% are likely to adversely affect some performance tasks and moods, however, as well as induce AMS in about one-third of the exposed individuals. These effects are quite similar to those observed in mountain climbers at the same PO2, whose responses well may be predictive of the effects of oxygen concentrations in between 13 and 17% oxygen.

# INTRODUCTION

To reduce the risk of damage from fires and loss of life aboard submarines, naval engineers have suggested that the oxygen concentration be reduced below the normal ambient level of approximately 21% (25). Suggested oxygen concentrations have ranged from 19 to 13% oxygen (13,25). Air with 17% oxygen has an oxygen partial pressure (PO2) of 129 torr, equivalent to 5,600 feet, which is approximately that of Denver, CO. Medically normal residents of that city live, work, and play without noteworthy detrimental effects. On the other hand, air with 13% oxygen has a PO2 of 99 torr, equivalent to that at 12,600 feet. This level of altitude has been shown to have detrimental effects on performance (4,14,18,19,31) and mood states (1,8,30), and causes symptoms of acute mountain sickness (AMS) (10,20,21,22).

There is an extensive literature documenting the effects of altitude on cognitive performance. The threshold altitudes for performance decrements on mental performance tasks and the magnitude of the impairments vary with the difficulty and complexity of the task to be performed (14). Tune (31) has reported that visual sensitivity is less and dark adaptation takes longer at altitudes as low as 5,000 to 7,000 feet, while Ernsting (16) found that night vision and immediate memory are significantly impaired at 6,000 to 8,000 feet. Denison et al.(15) found that performance of a novel psychomotor task was impaired as low as 8,000 feet, but after evaluating this work, Fowler et al. (18) suggested that the minimum altitude at which hypoxic performance decrements can be detected consistently is likely to be greater than 8,000 feet. Most cognitive, motor, and affective changes occur at altitudes greater than 10,000 feet (31); above this altitude, motor movements are slowed, memory is less reliable, and thinking becomes confused and difficult.

Cognitive decrements follow a specific time course at altitude. Cognitive

performance can be degraded as soon as 1-6 hours after exposure, hours before the onset of altitude sickness (3,14). Initial impairments are then followed by progressive return to baseline. One study (3) found decrements on all seven cognitive tasks as soon as tested, one or six hours after ascent to 15,000 feet. An altitude of 13,800 feet produced decrements on about half of the cognitive tasks administered within 1.5-4.5 hours after ascent (4). The impairment in performance has been shown to result both from increased errors (17) and decreased rates, i.e., the number of problems completed per unit time (6,7,19).

Less is known about the effects of altitude on mood states. Observed behaviors and personal anecdotes suggest that ascents to altitudes above 8,000 feet cause changes in mood. The initial euphoria at higher altitudes is followed by depression and then, with time, individuals may also become quarrelsome, irritable, and apathetic (32). Banderet reported mood changes, as measured by the Clyde Mood Scale, after 19 hours at 14,110 feet (1). A more detailed analysis of these changes (30) showed that mood scores were adversely affected with continued altitude exposure and this time course was similar to the time course for symptoms of AMS. Mood changes were related to both altitude achieved and duration of exposure. The moods adversely affected in both these studies were "Clear Thinking", "Sleepiness", "Dizziness", and "Friendliness".

The symptoms of AMS are principally headache, anorexia, nausea, vomiting, insomnia, lassitude, and general malaise (10,20). They appear in susceptible individuals within 4 to 8 hours if the partial pressure of oxygen (PO2) is reduced below about 110 torr, equivalent to an altitude of 10,000 feet (23). The lower the PO2 below this threshold and the shorter the time spent at intermediate PO2 levels, the greater the incidence and severity of the resulting symptoms. In uncomplicated cases these symptoms are self-limited, disappearing within a few days to a week as the body acclimates to the reduced PO2 (21,22). The PO2 of normal ambient air (21% oxygen) at sea level pressure is 159 torr; the PO2 of 17%

oxygen at sea level is approximately equivalent to normal air at 5,600 feet altitude, which will not induce AMS symptoms in normal individuals. The PO2 of 13% oxygen air at sea level is equivalent to that at 12,600 feet altitude, which will induce mild to moderate symptoms in 25-40% of unacclimated individuals. This same PO2 also results with 17% oxygen air if the ambient pressure is reduced from 760 to 576 torr. Since AMS symptoms can develop in as few as 4 hours (10,21), it is possible that such a pressure reduction may induce symptoms in susceptible individuals during exposures as short as an 8-hour work shift.

Studies using hypoxic gas mixtures can be compared to those conducted on mountains or in hypobaric chambers because a normobaric environment with a reduced oxygen concentration is comparable to the decreased oxygen partial pressure produced in a hypobaric atmosphere in causing symptoms of AMS. It is thought that cognitive functioning, mood states, and symptomatology would be affected similarly under conditions having the same PO2.

The purpose of this study was to test the hypothesis that individuals can live and work in a 17% oxygen atmosphere (PO2 = 129 torr) without experiencing appreciable decrements in cognitive performance, altered mood states, or altitude illness symptomatology, but not in a 13% oxygen atmosphere (PO2 = 99 torr). The effects of a 17% oxygen environment on these parameters at a pressure sufficient to reduce the PO2 to 99 torr for 7-8 hours were also evaluated, for comparison with the same PO2 in normobaric 13% oxygen.

## METHODS

### Subjects

Thirteen fully informed, male volunteers from the U.S. Navy and Marine Corps completed this study. They ranged in age from 18-36 years with a mean age of 23.8 years. A fourteenth volunteer, removed from the chamber during the 13%

oxygen condition because of respiratory infection and fever, was not included in any analyses. The group mean was used when missing data occurred (one subject on day 1 at 13% oxygen who did not complete the morning tests because of a febrile illness and another subject on day 3 at 17% oxygen who was excluded from exposure to hypobaric pressure because of a previous mastoidectomy).

## Assessment Instruments

A variety of timed tasks were used to assess cognitive performance; sample items are shown in Figure 1. Five paper and pencil tasks (Addition, Coding, Computer Interaction, Map/Compass, and Pattern Comparison) were administered manually, while three tasks (Number Comparison, Pattern Comparison, and Pattern Recognition) were given on portable computers (Grid Compass II, Model 1131). The Computer Interaction and Map/Compass tasks were developed in our laboratory (2), while the remaining tasks were developed as part of the Navy's Performance Evaluation Tests for Environmental Research (PETER) program (9,11). The computerized versions of the Pattern Comparison and Pattern Recognition tasks were used for the first time in this study; all the others have been shown previously to stabilize with practice and to be sensitive to a variety of environmental stressors (5,7,24,26). All paper and pencil tasks were available in 15 alternate forms. The computerized tasks were developed to closely parallel their paper and pencil counterparts.

The performance tasks used in this experiment require cognitive processes inherent in many real-world tasks (Figure 1). Addition requires summing three two-digit numbers. Coding requires writing the appropriate number for each "test" symbol from the information in the legend at the top of the page, similar to manual procedures for encoding communications. Computer Interaction requires using a 12-digit desk top calculator (not a computer) with liquid crystal display (Radio Shack EC-2004) to solve arithmetic problems. This task evaluates a

person's global interactions with both numeric keyboards and display systems. Map/Compass requires abstraction of direction, azimuth, and distance relationships, conceptualization of changing spatial relationships, and the ability to calculate distances travelled or new locations using grid coordinates. Number Comparison requires identifying and recording whether two numbers are the same or different, which is similar to comparing part numbers, grid coordinates, or numbers on property inventories. Pattern Comparison requires identifying whether two asterisk patterns are the same or different. Both patterns have the same number of asterisks and on some problems a single asterisk is displaced one space. The demands of this task are similar to evaluating object displacement between successive reconnaissance photographs. Pattern Recognition requires identifying a pattern (histogram) that is identical to the sample pattern from an array of eight alternatives. This task is similar to recognizing electronic, computer programming, or map symbols.

The Clyde Mood Scale (12), administered on portable computers, was used to measure subjects' moods. This scale consists of 48 adjectives, e.g., "kind", "alert", "lonely", self-rated on a four-point scale ("not at all", "a little", "quite a bit", and "extremely"). Prior analysis has shown that the 48 adjectives cluster into six principal mood factors - Friendliness, Aggressiveness, Clear Thinking, Sleepiness, Unhappiness, and Dizziness (12). Mood, as measured by this scale, has been shown previously to be affected by high altitude (1,30).

The presence and severity of AMS symptoms were assessed by means of the Environmental Symptoms Questionnaire (ESQ), a 67-item instrument (28) administered in card format. Resting arterial blood oxygen saturations were determined from a direct reading, pulse oximeter (Novametrix model 500, Wallingford, CT) positioned on the index finger of the non-preferred hand.

## Procedures

Research Design. This experiment was part of a larger study; the overall research design and other aspects of the study are described in Knight and Callahan (25). For this portion of the study, the research design was as described below.

The subjects were investigated in two groups of seven tested a month apart. Extensive training and practice were given on all cognitive tasks for six to eight training days, which immediately preceded the experimental period. Subjects were usually trained twice daily, for 60 minutes each morning and afternoon. All subjects were seated at tables and trained and tested as a group.

During training, the Addition, Coding, Number Comparison, Pattern Comparison (paper and computer), and Pattern Recognition tasks were given for three minutes, the Map/Compass task for four minutes, and the Computer Interaction task for six minutes. Performance feedback was provided to the subjects after each session and extensive practice was given on all tasks to ensure that performance was stable prior to the experimental phase of the study. Subjects were instructed to respond as rapidly as possible, even though making some errors (< 8%). Subjects were also familiarized with the use of the mood and ESQ symptomatology scales during the training week.

For the fifteen-day experimental testing period subjects were continuously confined to the USARIEM hypobaric chamber, where they lived for three days at each of the following oxygen concentrations: 21, 17, 21, 13, and 21%. The required changes in oxygen concentration every third day (e.g., from 21% to 17% and back to 21%) took place slowly while the subjects were sleeping, over the period 0100 to 0500 hours. All atmospheres contained 0.9 $\pm$ 0.2% carbon dioxide; the balance was pure nitrogen. The barometric pressure was ambient, ranging from 744 to 771 torr, except for 7.5 hours on day 3 at 17% oxygen when the pressure was reduced to 576 torr (beginning at 1300 hours) to produce a $PO_2$ of 99 torr.

Different cognitive task batteries were administered morning and afternoon during the 30-minute sessions. During the morning session, the Computer Interaction, Pattern Comparison (paper), Pattern Comparison (computer), and the Pattern Recognition tasks were given. During the afternoon session, the Addition, Coding, Map/Compass, and Number Comparison tasks were given. The afternoon tasks were administered every day, but due to other project requirements, the morning tasks could only be administered on the first and third day at each oxygen concentration. On the first day of exposure to a new oxygen concentration subjects were tested at 0800 and 1300 hours. The second day they were tested only at 1400 hours. On the third and final day, subjects were tested at 0900 and 1400 hours. The Map/Compass task was given for the same duration as in the training sessions, while the Number Comparison task was given for an additional two minutes; all other tasks were given for an additional minute.

The Clyde Mood Scale was administered each afternoon after the cognitive tasks. The ESQ was administered each day just before the evening meal. Determinations of resting arterial blood oxygen saturation were made on the afternoon of the second day of each three-day exposure period for all subjects and also on the third day of the 13% oxygen exposure period for six subjects.

Analysis. A measure of cognitive performance was derived to reflect the combined effects of changes in both rate and accuracy. It was calculated as number of problems correct/minute = (number of problems attempted - (number of problems incorrect * weighting factor))/number of minutes tested. The weighting factor, appropriate for the number of response alternatives on each task, was included to penalize for guessing.

Performance scores for each task at 17 and 13% oxygen were compared to the mean of the performance scores from the control periods at 21% oxygen before and after the condition with the lowered oxygen concentration. Mood scores at 17 or 13% oxygen were also compared to their appropriate control values. These scores

were submitted to two statistical analyses. The first was a one-way repeated-measures analysis of variance (ANOVA) to determine whether there were overall differences for the 17 or 13% oxygen condition. Then, post hoc comparisons were performed with the Newman - Keuls test to identify which daily values at 17 or 13% oxygen were different than the control. A significance level of $p \leq .05$ was chosen for all statistical tests.

The individual ESQ items identified as AMS symptoms were consolidated to produce scores for the cerebral and respiratory forms of AMS (AMS-C and AMS-R, respectively) by the weighting and summing method of Sampson et al. (27). By Sampson's criteria, scores exceeding a threshold of 0.6 for AMS-C or 0.7 for AMS-R are considered to be within the 95% confidence limits for the presence of that form of AMS. Scores were then averaged for the groups being either sick or well, under these criteria.

## RESULTS

Shown in Table 1 are means and standard deviations for the control periods and daily experimental periods for each cognitive task for all subjects combined. No decreases in performance were observed at 17% oxygen, including day 3 when the reduction in ambient pressure occurred. There were a number of significant overall effects for the cognitive tasks. However, post hoc comparisons revealed that cognitive performance was decreased by the 13% oxygen concentration on only one task; scores on the Computer Interaction task were significantly less than the control value on the first day at 13% (see Figure 2). All other post hoc comparisons revealed that cognitive performance was significantly improved over the corresponding control values, such as Addition on days 2 and 3 at 13%, Coding on day 2 at 17%, Number Comparison on day 3 at both 17% and 13%, Pattern Comparison (paper) on day 3 at 17%, and Pattern Comparison (computer) on day 3 at

17%.

Shown in Table 2 are means and standard deviations for the control periods and daily experimental periods for all subjects combined for each mood factor for each day at 17 and 13% oxygen. Mood did not change under the normobaric 17% oxygen condition. Post hoc comparisons of significant overall effects revealed that two mood factors were affected by the reduction in pressure on day 3 at 17% oxygen; Clear Thinking was decreased (Figure 3) and Dizziness was increased (Figure 4) from control values on this day. These differences resolved after the oxygen concentration was returned to 21%. Two mood factors were affected on day 1 at the 13% oxygen concentration: both Sleepiness (Figure 5) and Dizziness (Figure 6) scores increased. However, by day 2, both mood scores had returned to control values.

AMS-C and AMS-R scores are presented in Table 3 for the three control and two low oxygen experimental periods, along with the associated blood oxygen saturation levels for that period. For ready comparison across conditions, the subject group was divided into sick and well subgroups, based on their AMS-C scores during each experimental period. (Therefore, statistical tests of differences between groups in AMS scores are not relevant, as the groups were defined on the basis of that parameter). The average AMS scores and saturation values were then determined for each subgroup during each experimental period and the relevant control periods before and after. During the 17% oxygen experimental period, no subjects reported AMS-C or AMS-R scores in the sick range until the third day, when the PO2 was reduced to 99 torr for 7.5 hours. When tested at the end of this period, two subjects reported AMS-C scores of a mild to moderate degree of illness (group average $\pm$ SD = 1.0 $\pm$ 0.1). One of these two also had AMS-R, while the other reported several AMS-R symptoms (average = 0.7 $\pm$ 0.4). For comparison, the average values in the non-sick group were 0.2 $\pm$ 0.2 for both AMS-C and AMS-R, scarcely different from the control values, or even

those just prior to the pressure being reduced. Resting blood oxygen saturation values on the second day at 17% oxygen were just at 97% for both groups, which represented a 1% decrease from the 98% achieved by both groups during the preceding and succeeding control periods ($0.05 \leq p \leq 0.1$). Saturation values were not taken during the period of hypobaria on the third day.

On the initial day of the 13% oxygen exposure period (PO2 = 99 torr), 17 hours after the oxygen concentration was reduced, 5 of the 13 subjects reported AMS-C scores above the threshold for illness. Four of the five also reported AMS-R scores above the illness threshold. The average scores for the ill group were 1.4 $\pm$ 0.6 for AMS-C and 1.0 $\pm$ 0.6 for AMS-R. The eight non-sick individuals, in contrast, averaged 0.3 $\pm$ 0.2 for AMS-C and 0.3 $\pm$ 0.3 for AMS-R. The sick group improved markedly by the second day under 13% oxygen; only two subjects remained ill. The AMS-C scores for both individuals were 0.8, only mildly ill, while the AMS-R scores averaged 1.2 $\pm$ 0.6 which indicated moderate illness. On the third day the AMS-C scores for these two were less than the threshold for illness, but the AMS-R scores, although improved, still remained above threshold.

The oxygen saturation values on the second day at 13% oxygen averaged 92.5 $\pm$ 1.0% for the sick group versus 91.7 $\pm$ 2.5% for the well group (not different). Saturation values on the third day averaged 93.5 $\pm$ 0.7 and 91.8 $\pm$ 1.2% (not different) for the sick and well groups, respectively. These results indicated not only no disadvantage to the sick group in their degree of oxygen saturation but also that both groups experienced increasing oxygen saturation with progressive acclimation to the hypoxic environment. Upon return to 21% oxygen, those individuals formerly sick averaged 98.5 $\pm$ 1.0% saturation, while their well counterparts averaged 97.8 $\pm$ 1.0%, similar to their control values. Again the sick group showed no disadvantage in saturation.

## DISCUSSION

These results indicate that performance was decremented on only one task, Computer Interaction, and only on the first day at 13% oxygen concentration. In contrast, several cognitive tasks showed progressively enhanced performance with increased days at a specific oxygen concentration, four tasks at 17% and six tasks at 13%. These enhancements cannot be attributed to insufficient training since correlation values between the last training administration and the first administration at 21% oxygen ranged from 0.63 to 0.94 (mean = 0.78) for all cognitive tasks, with the exception of the Coding task. The observed, increasing, linear trends provide additional evidence that performance on the cognitive tasks was not impaired by the lower oxygen concentrations.

Other studies using the same tasks as in the present study demonstrated performance decrements at altitudes of 13,800 to 15,500 feet (3,4,7,24). Such sensitivity to altitude shown by these tasks suggests that we would have been able to identify possible performance decrements at 13% oxygen. It is also of interest that the Computer Interaction impairment was measured at 0800 hours, three hours after the oxygen concentration in the chamber reached 13%. If this decrement was, in fact, caused by the lowered oxygen concentration, this result is consistent with the finding that cognitive performance may be affected by altitude as soon as 1-6 hours after ascent (3,4,14).

We have a speculative reason as to why performance on the Computer Interaction task was the only one decremented by 13% oxygen. The subjects reported themselves as being more sleepy on this first day at 13% oxygen; the Computer Interaction task was the first to be given in the morning session. It may have taken the subjects longer to "get going" that morning, thus adversely affecting Computer Interaction scores without affecting tasks performed later

that same day.

With respect to mood states, the 17% oxygen concentration had no adverse effect on mood states at normal barometric pressure. However, both Dizziness and Clear Thinking were adversely affected one hour after the reduction in ambient pressure on the third day at 17% oxygen. When measured after eight hours at 13% oxygen, Dizziness and Sleepiness scores were increased. Mood states could have been affected earlier at 13% oxygen, but this was the first administration at this condition, limiting our ability to determine at what point in time these changes occurred. The mood states of Friendliness, Clear Thinking, Dizziness, Sleepiness, and Unhappiness have been shown to be altered as early as from one to four hours after ascent to 14,110 feet (30). Our finding of significant adverse changes after eight hours at 12,600 feet supports the view that the alteration in mood occurs early in the exposure, rather than late. Other altitude studies using the Clyde Mood Scale also showed that the factors of Clear Thinking, Dizziness, and Sleepiness were those adversely affected by altitudes between 14,000 and 25,000 feet (1,8,30). Our results confirm that these three factors are more sensitive to altitude changes than the remaining factors.

All AMS scores seen during the control periods were well below the thresholds for illness, even those reported on the first day of recovery after the periods of hypoxic exposure. During the two days of exposure to 17% oxygen at normal atmospheric pressure, both AMS scores increased slightly, but not to illness thresholds. On the third day, after 7.5 hours at PO2 = 99 torr, two subjects reported scores indicative of AMS-C; one of these also reported AMS-R. These results are quite similar to the experience of mountain climbers. Oxygen pressure of 129 torr is equivalent to an altitude of 6,000 feet, which does not induce AMS in normal individuals; 99 torr is equivalent to 12,600 feet, which is sufficient to induce AMS in some individuals after 7-8 hours (20,22).

After 11 hours in the 13% oxygen environment, five of the thirteen subjects

reported AMS-C. Of these, four also reported AMS-R. After another 24 hours, three of the initial five no longer suffered from AMS and the two still sick had lower scores. These two showed continued improvement on day 3 at 13%, but still had scores indicative of illness. This is typical of 12,600 foot environments, in which about 30-40% of climbers will be affected by AMS, most of these recovering rapidly. Of the two subjects remaining ill for all three days, one had been sick during the previous hypobaric 17% oxygen exposure, but the other had not. Interestingly, it was the less severely ill of the two who had also suffered AMS-C during the hypobaric 17% oxygen exposure. This is not unusual; onset of altitude illness is unrelated to severity.

The progressive improvement in all individuals initially ill on the first of the three days' exposure to 13% oxygen followed the typical pattern of natural acclimatization to hypobaric hypoxia (21,22). Those least affected were recovered by the second day of exposure, while those most affected still had symptoms on the third day, albeit with progressively less severity. It appears, therefore, that about a third of the individuals exposed to normobaric atmospheres containing only 13% oxygen will experience AMS, but most will recover quickly. Few individuals, if any, will suffer AMS in 17% oxygen at normal pressures, but about one-fifth can be expected to experience AMS if the ambient pressure is reduced to 576 torr for 7-8 hours. It appears possible to estimate the AMS incidence at other combinations of ambient pressure and oxygen concentration from the experience of mountain climbers at the same altitude equivalent (22).

The blood oxygen saturation values obtained at rest during the 17% and 13% oxygen conditions indicated no relationship to AMS. Indeed, average saturation values at 13% of the sick individuals were numerically higher than the average of their well counterparts. Similarly, there was no suggestion that those later to be ill during the hypoxic exposure were so predisposed by having lower saturation

values during the preceding control period; the control values of those later to be sick also averaged numerically higher than those of the well group. An association between AMS and desaturation at rest has been shown in more severely hypoxic environments (20,21), however, and it has been proposed that the profound desaturation that occurs as a result of breathing disturbances during sleep in hypoxic environments is a primary cause of AMS (22). Our saturation measurements, taken during seated rest, cannot give any indication of the degree of desaturation experienced during sleep, of course. These well might have differed between the ill and the well groups. However, the AMS experienced after 7.5 hours exposure to the hypobaric 17% oxygen environment in the afternoon could not have been influenced either by sleep, because the subjects were awake throughout, or any differences in the preceding oxygen saturation, because there were none. It is clear, therefore, that susceptibility to AMS must be influenced by at least one factor other than arterial desaturation at the relatively low degree of hypoxia induced by a PO2 of 99 torr.

In summary, the most severe atmospheric condition tested, 13% oxygen, may produce short-term decrements in cognitive functioning and mood, lasting a day or so, and moderate AMS symptoms in some individuals. An atmosphere of 17% oxygen with a reduction in pressure could initially have an adverse effect on mood states and AMS symptomatology. An atmosphere of 17% oxygen alone does not appear to produce any differences in cognitive performance, mood states, or AMS symptomatology, and may, therefore, be a reasonable means for increasing fire safety aboard ship.

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TABLE 1. COGNITIVE TASK PERFORMANCE FOR 17 AND 13% OXYGEN CONCENTRATIONS

Number problems correct/minute (mean $\pm$ standard deviation)

| | | 17% oxygen | 13% oxygen |
|---|---|---|---|
| | | AFTERNOON TASKS | |
| ADDITION | | | ** |
| | Control | 10.02 ± 1.95 | 10.60 ± 1.83 |
| | Day 1 | 9.83 ± 2.34 | 10.77 ± 1.96 |
| | Day 2 | 10.29 ± 2.16 | 11.50 ± 2.18* |
| | Day 3 | 10.10 ± 2.13 | 11.51 ± 2.36* |
| CODING | | ** | * |
| | Control | 38.80 ± 2.35 | 38.89 ± 2.72 |
| | Day 1 | 38.98 ± 2.84 | 38.12 ± 4.22 |
| | Day 2 | 42.91 ± 4.84** | 40.05 ± 4.18 |
| | Day 3 | 37.01 ± 3.49 | 41.41 ± 4.28 |
| MAP/COMPASS | | | ** |
| | Control | 5.39 ± 1.41 | 6.67 ± 1.85 |
| | Day 1 | 4.99 ± 1.37 | 6.67 ± 2.33 |
| | Day 2 | 5.40 ± 1.65 | 7.17 ± 1.91 |
| | Day 3 | 5.32 ± 1.82 | 7.19 ± 1.94 |
| NUMBER COMPARISON | | ** | ** |
| | Control | 23.43 ± 4.12 | 24.52 ± 4.13 |
| | Day 1 | 22.92 ± 3.78 | 23.75 ± 4.03 |
| | Day 2 | 24.15 ± 4.65 | 25.00 ± 4.78 |
| | Day 3 | 25.52 ± 3.89** | 26.38 ± 4.87** |
| | | MORNING TASKS | |
| COMPUTER INTERACTION | | | ** |
| | Control | 2.40 ± 0.58 | 2.53 ± 0.55 |
| | Day 1 | 2.38 ± 0.67 | 2.18 ± 0.63** |
| | Day 3 | 2.45 ± 0.60 | 2.65 ± 0.56 |
| PATTERN COMPARISON (PAPER) | | ** | |
| | Control | 13.01 ± 3.18 | 13.77 ± 2.91 |
| | Day 1 | 12.85 ± 3.88 | 14.27 ± 3.13 |
| | Day 3 | 14.38 ± 3.33** | 13.80 ± 3.38 |
| PATTERN COMPARISON (COMPUTER) | | * | * |
| | Control | 14.05 ± 3.43 | 14.71 ± 3.66 |
| | Day 1 | 14.99 ± 4.08 | 13.88 ± 4.26 |
| | Day 3 | 15.58 ± 3.87* | 15.81 ± 3.98 |
| PATTERN RECOGNITION | Control | 11.01 ± 1.58 | 11.86 ± 1.74 |
| | Day 1 | 10.62 ± 1.69 | 11.90 ± 1.75 |
| | Day 3 | 11.01 ± 1.59 | 12.38 ± 1.77 |

NOTE: Asterisks above the entries indicate significant overall effects compared to control (e.g., 17% vs. 21% oxygen) while asterisks to the right of an entry indicate daily differences from control values (*=$p \leq .05$, **=$p \leq .01$). The barometric pressure was reduced to 576 torr on the afternoon of day 3 at 17% oxygen to produce a condition similar to that at 13% oxygen.

TABLE 2. MOOD STATES FOR 17 AND 13% OXYGEN CONCENTRATIONS

Factor scores (mean ± standard deviation)

| | | 17% oxygen | 13% oxygen |
|---|---|---|---|
| FRIENDLINESS | | | |
| | Control | 48.13 ± 10.38 | 50.23 ± 8.11 |
| | Day 1 | 49.08 ± 14.71 | 47.16 ± 9.86 |
| | Day 2 | 48.91 ± 15.06 | 50.91 ± 7.44 |
| | Day 3 | 49.46 ± 12.78 | 48.97 ± 8.46 |
| AGGRESSIVENESS | | | |
| | Control | 56.61 ± 7.95 | 56.00 ± 9.28 |
| | Day 1 | 54.58 ± 8.23 | 53.55 ± 9.10 |
| | Day 2 | 55.38 ± 7.93 | 54.59 ± 9.76 |
| | Day 3 | 55.12 ± 7.34 | 57.15 ± 9.55 |
| CLEAR THINKING | | * | |
| | Control | 52.27 ± 8.64 | 50.63 ± 7.68 |
| | Day 1 | 50.95 ± 8.22 | 49.90 ± 7.75 |
| | Day 2 | 50.79 ± 11.44 | 50.05 ± 7.02 |
| | Day 3 | 47.20 ± 9.85* | 50.55 ± 8.40 |
| SLEEPINESS | | * | ** |
| | Control | 54.34 ± 7.89 | 51.37 ± 7.15 |
| | Day 1 | 56.04 ± 12.09 | 58.58 ± 9.91** |
| | Day 2 | 51.83 ± 12.69 | 52.78 ± 9.21 |
| | Day 3 | 60.44 ± 9.93 | 51.88 ± 9.20 |
| UNHAPPINESS | | | |
| | Control | 43.30 ± 4.20 | 43.47 ± 5.12 |
| | Day 1 | 41.66 ± 4.30 | 42.54 ± 4.92 |
| | Day 2 | 43.67 ± 5.48 | 42.92 ± 5.22 |
| | Day 3 | 41.46 ± 4.67 | 43.28 ± 5.14 |
| DIZZINESS | | ** | ** |
| | Control | 47.38 ± 4.33 | 48.30 ± 4.28 |
| | Day 1 | 48.42 ± 8.09 | 57.25 ± 8.23** |
| | Day 2 | 49.26 ± 5.72 | 49.33 ± 8.52 |
| | Day 3 | 56.84 ± 7.57** | 46.81 ± 6.46 |

NOTE: Asterisks above the entries indicate significant overall effects compared to control (e.g., 17% vs. 21% oxygen) while asterisks to the right of an entry indicate daily differences from control values (*= $p \leq .05$, **= $p \leq .01$). The barometric pressure was reduced to 576 torr on day 3 at 17% oxygen to produce a condition similar to that at 13% oxygen.

Table 3: Environmental conditions, AMS scores, and blood $O_2$ saturations for 3-day control and experimental periods.

| PARAMETER | | CONTROL I | EXPERIMENTAL I | | | CONTROL II | EXPERIMENTAL II | | | CONTROL III |
|---|---|---|---|---|---|---|---|---|---|---|
| | | DAY 2 | DAY 1 | DAY 2 | DAY 3 | DAY 2 | DAY 1 | DAY 2 | DAY 3 | DAY 2 |
| $O_2$ (%) | | 21 | 17 | 17 | 17 | 21 | 13 | 13 | 13 | 21 |
| $P_B$ (torr) | | 760 | 760 | 760 | 576 | 760 | 760 | 760 | 760 | 760 |
| $P_{O2}$ (torr) | | 159 | 129 | 129 | 99 | 159 | 99 | 99 | 99 | 159 |
| Number: | sick | 0 | 0 | 0 | 2 | 0 | 5 | 2 | 2 | 0 |
| | well | 13 | 13 | 13 | 11 | 13 | 8 | 11 | 11 | 13 |
| AMS-C: | sick | (0.2±0.2) | (0.2±0.1) | (0.2±0.2) | 1.0±0.1 | (0.0±0.1) | 1.4±0.6 | 0.8±0.0 | 0.6±0.6 | (0.1±0.1) |
| | well | (0.0±0.1) | (0.1±0.2) | (0.1±0.1) | 0.2±0.2 | (0.0±0.0) | 0.3±0.2 | 0.2±0.3 | 0.0±0.1 | (0.0±0.1) |
| AMS-R: | sick | (0.2±0.1) | (0.2±0.2) | (0.2±0.3) | 0.7±0.4 | (0.1±0.1) | 1.0±0.6 | 1.2±0.6 | 0.8±0.2 | (0.1±0.1) |
| | well | (0.0±0.1) | (0.1±0.2) | (0.1±0.1) | 0.2±0.2 | (0.1±0.1) | 0.3±0.3 | 0.2±0.1 | 0.2±0.2 | (0.1±0.1) |
| $S_aO_2$: (torr) | sick | (98.6±1.1) | n.d. | (97.0±0.0) | n.d. | (98.2±0.8) | n.d. | 92.5±1.0 | 93.5±0.7 | (98.5±1.0) |
| | well | (98.2±0.7) | n.d. | (97.3±0.9) | n.d. | (98.1±1.0) | n.d. | 91.7±2.5 | 91.8±1.2 | (97.8±1.0) |

Notes: n.d. = not determined on that day.
( ) = mean ± s.d. computed for sick or well group, based on AMS-C score during hypoxic exposure.

# FIGURE 1

## SAMPLE ITEMS FOR EACH COGNITIVE TASK

### ADDITION

| | | | | |
|---|---|---|---|---|
| 71 | 20 | 27 | 53 | 20 |
| 19 | 51 | 83 | 33 | 35 |
| 76 | 40 | 47 | 67 | 11 |

### CODING

NUMBER: 1 2 3 4 5 6 7 8
SYMBOL: O ▪ U - L X › /

L O › ▪ › L / O -
( ) ( ) ( ) ( ) ( ) ( ) ( ) ( ) ( )

### COMPUTER INTERACTION

73374 MINUS 30776.9 =
58.65 PERCENT OF 41930.9 =
7398.99 DIVIDED BY 54.88 =
8897 PLUS 69194765 =
4590.84 MULTIPLIED BY 271.1 =

### NUMBER COMPARISON

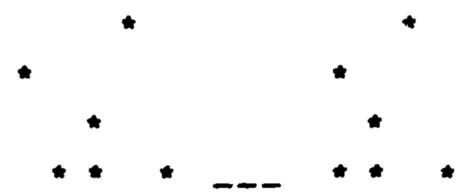
845793858_845793858
50237_20237
976_976
0623385_0623325
239055610_233055610

### MAP COMPASS

PVT LEE TRAVELS ON AN AZIMUTH OF 4? WHAT DIRECTION IS HE TRAVELING?
_SE _NW _S _N

A COMPANY IS AT GRID COORDINATE 112801. IF THEY MOVE SOUTH 1800 M WHAT IS THEIR NEW LOCATION?
_094801 _130801 _112819 _112783

### PATTERN COMPARISON



### PATTERN RECOGNITION

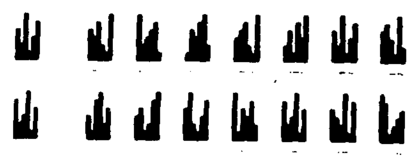
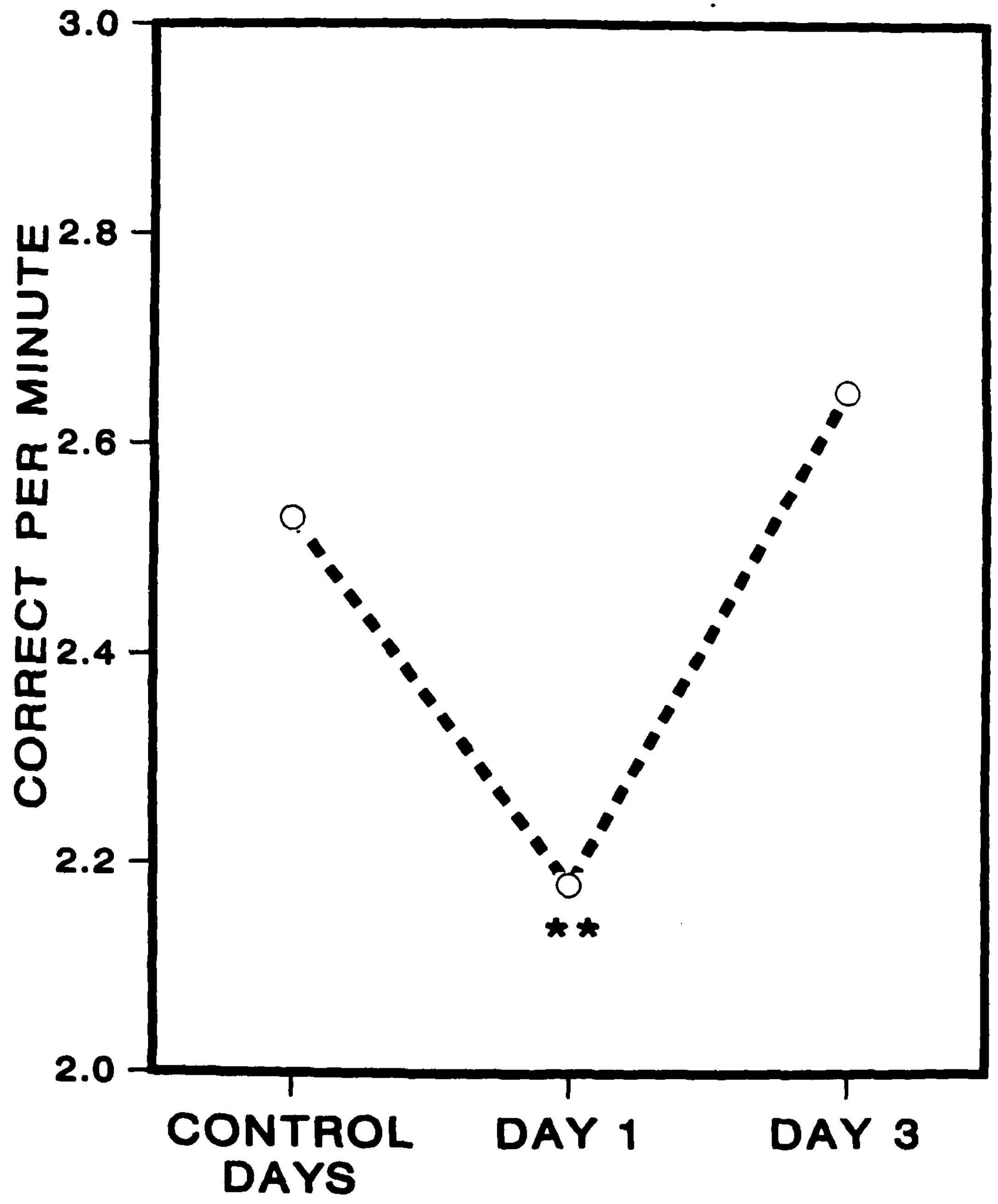


FIGURE 2
COMPUTER INTERACTION: 13% $O_2$



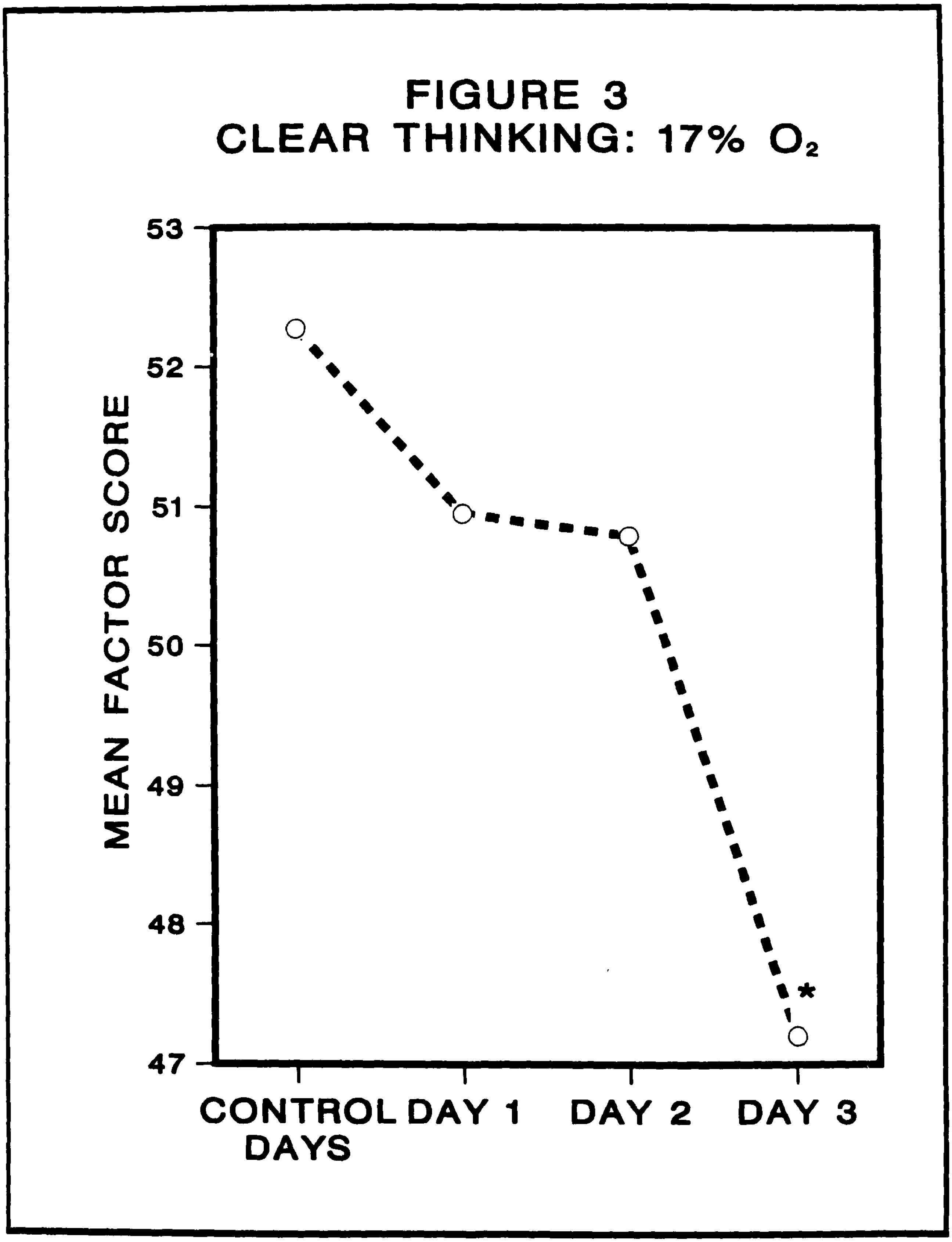


FIGURE 3
CLEAR THINKING: 17% $O_2$
53
52
51
50
49
48
47
MEAN FACTOR SCORE
*
CONTROL DAYS
DAY 1
DAY 2
DAY 3

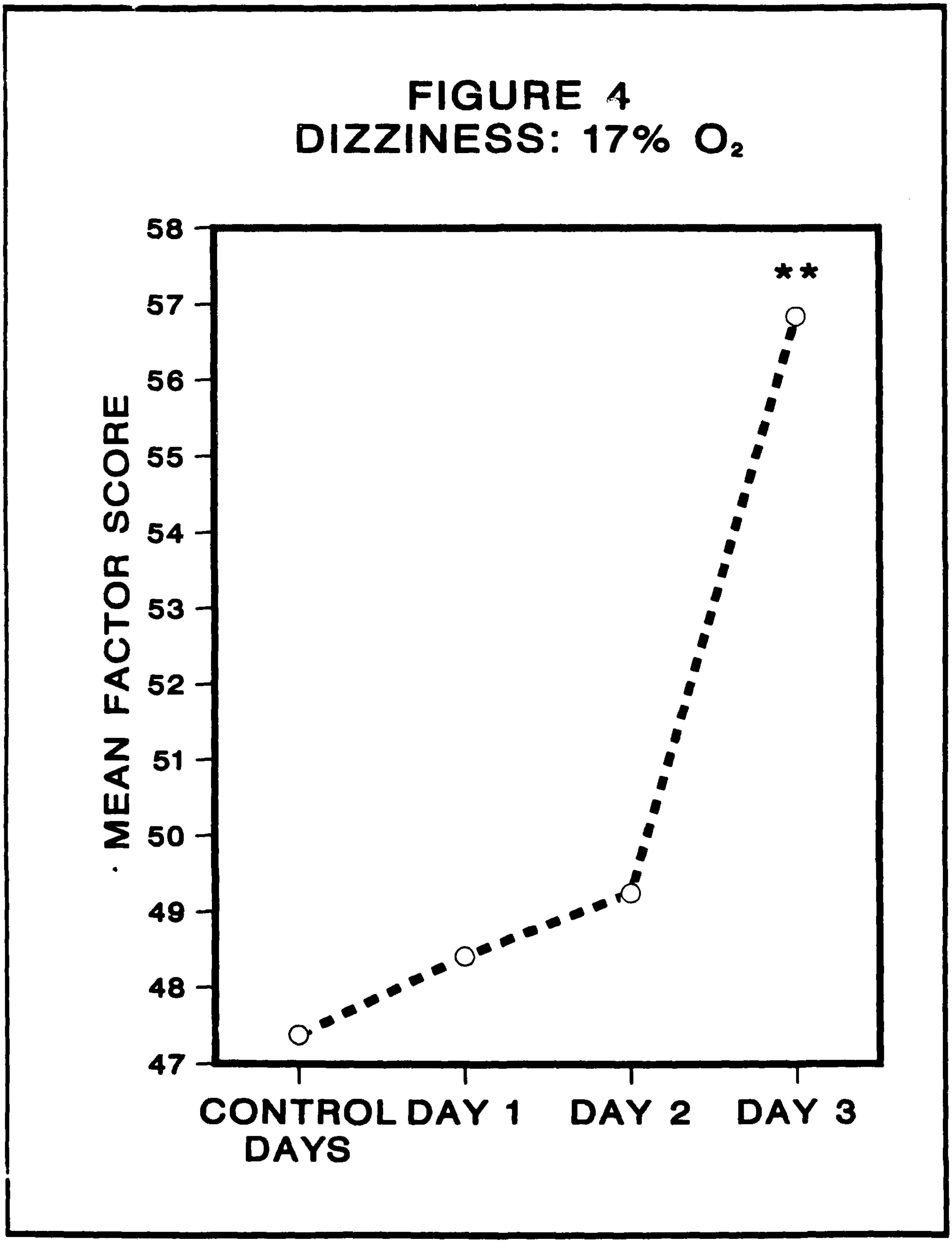


FIGURE 4
DIZZINESS: 17% $O_2$
MEAN FACTOR SCORE
58
57
56
55
54
53
52
51
50
49
48
47
**
CONTROL
DAY 1
DAY 2
DAY 3
DAYS

# FIGURE 5
# SLEEPINESS: 13% $O_2$

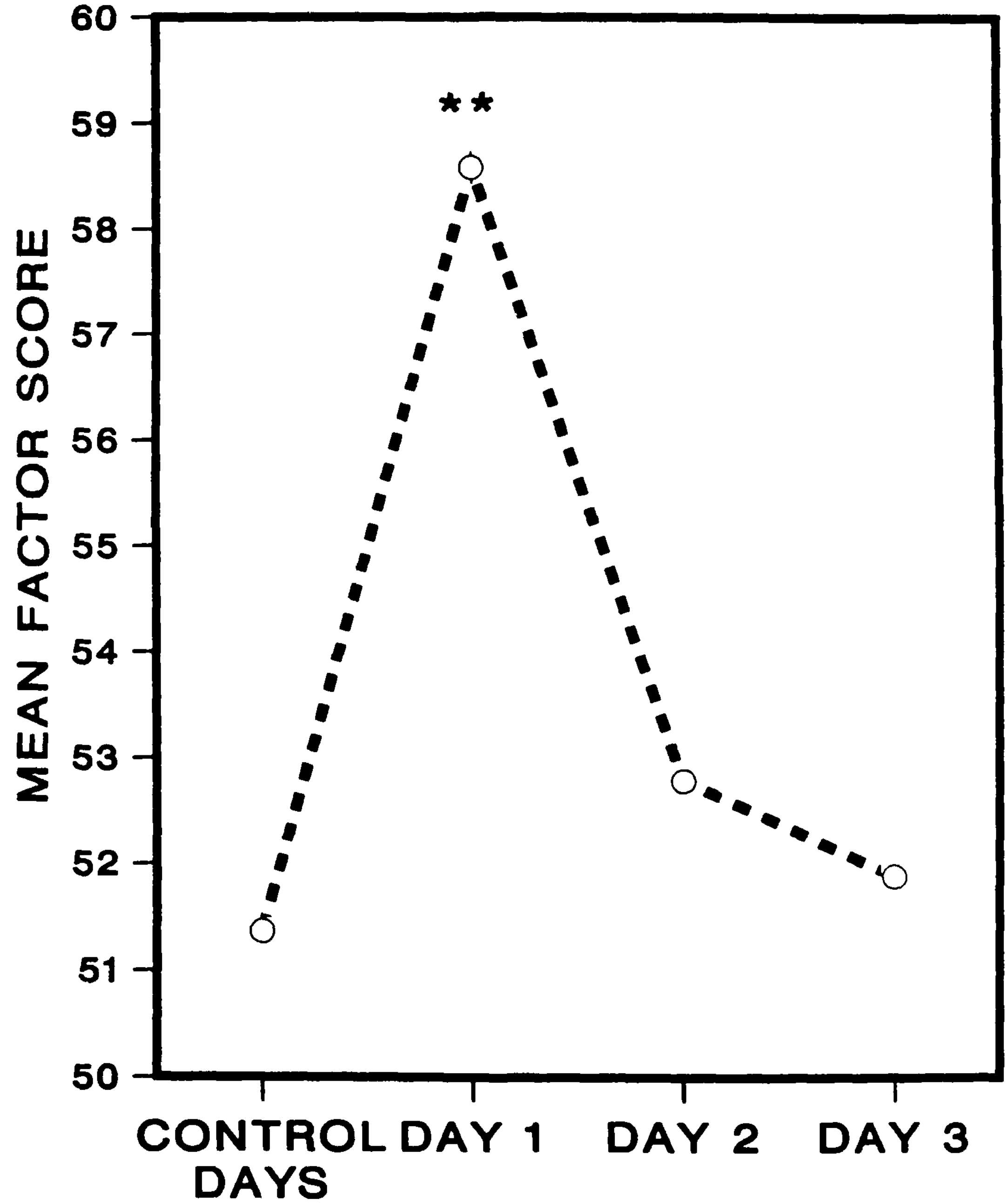
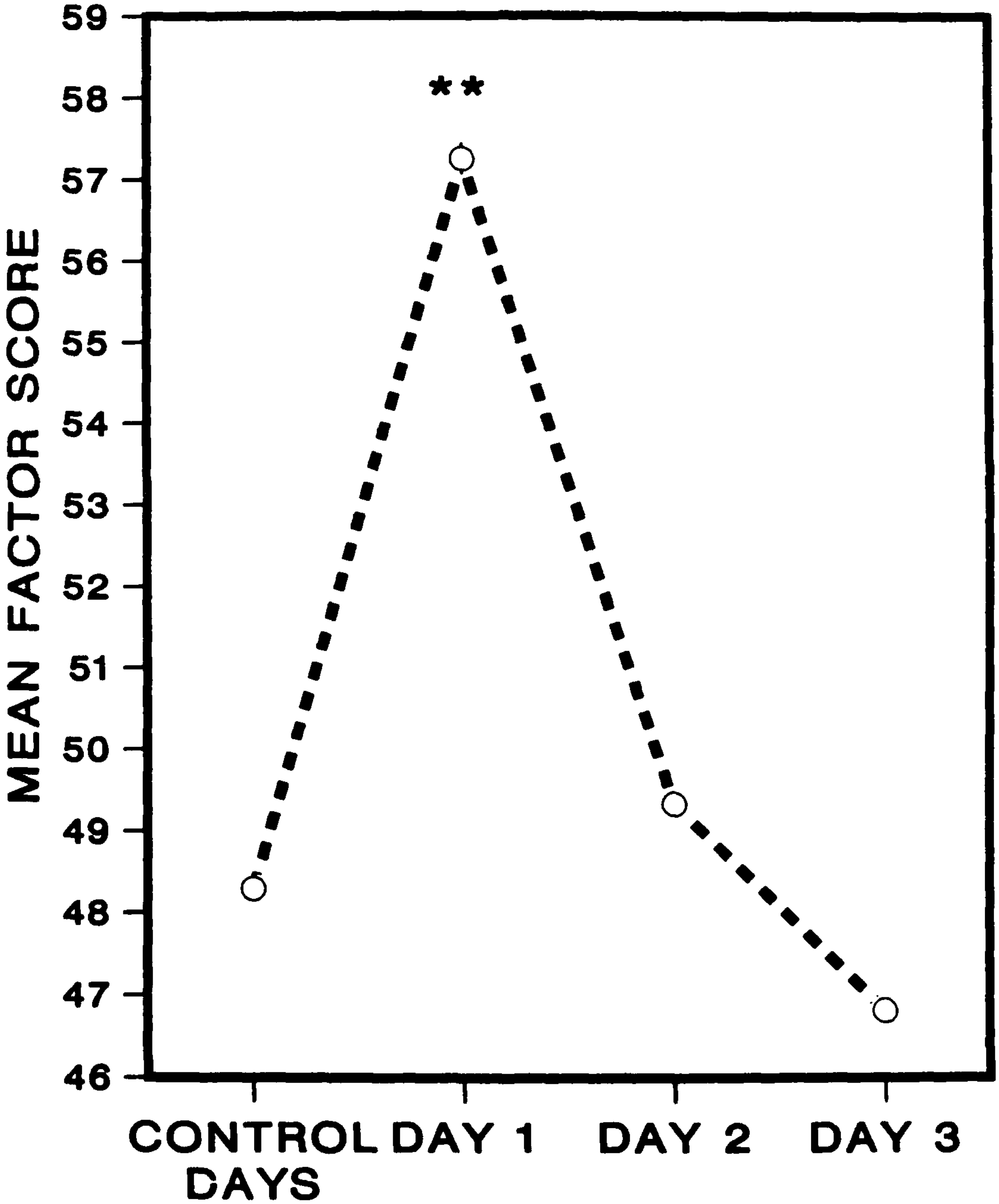


FIGURE 6
DIZZINESS: 13% $O_2$



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Dr. Carhart (1)
Naval Research Laboratory
Bldg. 207
4555 Overlook Ave. SW
Washington, D.C. 20375